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THE FAA/M.I.T. LINCOLN LABORATORY DOPPLER WEATHER RADAR PROGRAM

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1. INTRODUCTION

Adverse weather is the leading cause of aircraft accidents in the United States. In order to improve hazardous weather detection and warning capability for aviation, the Federal Aviation Administration (FAA) is pursuing a two part Doppler weather radar program. The first part consists of a joint program with the National Weather Service (NWS) and United States Air Force Weather Service (AWS) is to develop and install the Next Generation Weather Radar (NEXRAD). The NEXRAD Systems will meet the FAA en route hazardous weather detection requirements and will replace the existing obsolete NWS and AWS weather radars.

The second part of the FAA program is the development of a Terminal Doppler Weather Radar (TDWR), which could be procured and installed at major airports to detect weather hazards to terminal aviation operations. The TDWR could be either a derivative of NEXRAD or a separate radar system.

In order to support both of these efforts, the FAA contracted with M.I.T. Lincoln Laboratory to develop and fabricate a NEXRAD-like transportable weather radar support facility. This facility along with a second Doppler radar and a network of meteorological measurement stations are installed near Memphis, Tennessee. These facilities will be used to validate and refine scanning strategies, data processing techniques, and weather detection algorithms. The utility of weather radar products for air traffic control (especially for pilots and controllers) will be evaluated.

2. NEXRAD

The tri-agency (FAA, NWS, AWS) NEXRAD Program consists of four phases: system definition, validation, limited production, and full production. In the system validation phase, which was completed in 1983, three contractors each defined a system to meet the joint requirements of the three participating agencies. Two of these contractors, Raytheon and Sperry, were

selected to proceed with the validation phase and will each fabricate a prototype NEXRAD system for competitive evaluation. One contractor will be selected for limited production of 10 systems. Upon completion of operational test and evaluation using the winning contractor's prototype system, an option will be exercised for full production.

The NEXRAD System consists of three major subsystems. These subsystems are: Radar Data Acquisition (RDA), Radar Production Generation (RPG), and Principal User Product (PUP). The RDA subsystem includes the basic radar components such as antenna, transmitter, and receiver; clutter suppression; and signal processing required to generate base data (reflectivity, velocity, spectral width). The RPG subsystem includes all hardware/software required for real time generation, storage, and distribution of products for operational use. The products required by the FAA are listed in Table 1. Algorithms exist for the first seven of these products although refinements are being worked on for several of them. The FAA is sponsoring the development of algorithms to generate gust front and icing products. No work is presently being performed on a hurricane algorithm. The PUP subsystem includes the meteorologist work station for the display and annotation of products.

TABLE 1

FAA NEXRAD PRODUCTS

1. Layered Reflectivity
2. Layered Turbulence
3. Winds
4. Storm Movement Predictions
5. Hail
6. Mesocyclone
7. Tornado
8. Gust Fronts
9. Icing/Freezing Level
10. Hurricanes

The FAA's use of NEXRAD data differs from that of NWS and AWS. The NWS and AWS meteorologists will receive data on a continuous basis from one NEXRAD System, although other NEXRAD Systems can be addressed on a dial-up basis. The Center Weather Service Unit (CWSU) meteorologist assigned to the FAA Air Route Traffic Control Centers (ARTCC) is responsible for large geographic areas

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covered by up to 40 NEXRAD Systems. To accomplish this, the FAA is developing a Central Weather Processor (CWP) that will mosaic all the NEXRAD Systems feeding an ARTCC into a single display for use by the CWSU meteorologist. In addition to the CWSU meteorologist, the CWP will feed mosaiced weather radar data to pilots via a weather communications processor and ground/air data link, to controllers' displays through the advanced automation system, and to flight service stations. Figure 1 shows the NEXRAD data feed through the CWP to the aviation users. Because the CWSU meteorologist has a large geographic area to cover and because the other aviation users are non-meteorologists, it is essential that the NEXRAD generate fully automated products that do not require meteorological interpretation by the aviation users. The FAA must also develop concise, easily understandable display formats for these products.

The three participating agencies plan to jointly deploy NEXRAD Systems in a national network consisting of 113 sites in the continental United States. This network will provide the FAA with en route coverage above 5,000 feet AGL east of the Rocky Mountains and above 10,000 feet AGL in the mountainous areas west of the Rocky Mountains. In addition, the FAA plans to procure seven NEXRAD Systems for Alaska, three systems for Hawaii, and three systems for installation in the Caribbean area.

The NEXRAD program schedule is shown in Table 2.

TABLE 2

NEXRAD SCHEDULE

Prototype Delivery	Winter 1985/1986
Limited Production	Fall 1986
Contract Award	
First System Delivery	Spring 1988
Last System Delivery	Fall 1992

3. TERMINAL DOPPLER WEATHER RADAR

Results from the Joint Airport Weather Studies (JAWS) project indicate that microbursts pose a significant hazard to aviation in the terminal area. This phenomena consisting of a downburst of air, which spreads out in all directions upon hitting the ground, covers only a small area 1-2 kilometers wide. Microbursts can be either wet (precipitation hitting the ground) or dry and have a short lifetime of several minutes. A radar designed to detect microbursts must have the following features:

- Capability to detect weak signals (dry microburst)
- High level of clutter rejection
- Fast update rate on the order of 1 minute
- Siting near the airport to detect low altitude outflow
- Automatic generation of microburst products which are easily displayed to pilots and controllers

Although the NEXRAD System has the ability to incorporate these features, it cannot provide the needed update rate and still meet the requirements of the FAA, NWS, and AWS in a national network. The FAA is, therefore, exploring the use of a separate terminal Doppler weather radar to detect hazardous weather conditions at selected high density terminals. In addition to microbursts, the TDWR could also provide pilots and controllers information on gust fronts and other wind shears, turbulence, precipitation, and storm movements at a faster update rate than the NEXRAD system. The weather radar support facility discussed later in this paper will be used to resolve a number of TDWR operational issues. Among these issues are:

- Siting (on or off the airport)
- Optimum scanning strategy
- Optimum update rate
- Interface with air traffic control facilities

In addition, the support facility will be used to collect weather data from the Southeast United States and to develop a microburst algorithm. The proposed TDWR data flow is shown on Figure 1. Time critical wind shear/microburst data is displayed immediately to the controllers. The terminal controllers will also receive NEXRAD data such as hail and mesocyclones from the CWP.

The number of TDWR Systems to be procured and the schedule for procurement is not firm at this time due to funding uncertainties. The approach to be taken in TDWR procurement is also uncertain. Two possibilities are:

- Procure a derivative of NEXRAD sharing components, documentation, training, etc.
- Procure the TDWR separate from NEXRAD

4. WEATHER RADAR SUPPORT FACILITY

A principal element of the FAA/Lincoln program is the measurement systems currently in operation near Memphis International Airport as shown in Fig. 2. The S-band weather radar is intended to be functionally equivalent to a NEXRAD sensor. The key features of the S-band radar are as follows:

- a center fed 8.5 m diameter parabolic reflector antenna that achieves the NEXRAD objective of a 1 degree beam-width (BW) and -25 dB first sidelobes with the sidelobes at least 40 dB down for angles greater than 10 degrees from boresight.
- the computer controlled mount with peak angular velocities of 30 degrees/sec in azimuth, 15 degrees/sec in elevation, and peak accelerations of 15 degrees/sec² in both axes that can execute a variety of scan strategies.

3. a klystron transmitter with 1.1 MW peak power for 0.8 μ s pulses at rates up to 1200 pulses/sec. This klystron (from an ASR-8 System) has the spectral stability for 50 dB clutter suppression with polyphase modulation for range ambiguity resolution.
4. use of a low noise receiver to yield a sensitivity close to the NEXRAD objective of 0 dB SNR on a -8 dBz target at 50 km with an "instantaneous" AGC to yield a dynamic range of approximately 90 dB.
5. finite impulse response clutter filtering and auto-correlation lag estimation by a fixed-point arithmetic Lincoln-designed signal processor designed to achieve a clutter suppression of 50 dB.
6. execution of computationally intensive tasks such as conversion of auto-correlation values to weather estimates, data clean-up (e.g., clutter map editing, velocity dealiasing, etc.), resampling to a Cartesian grid and feature extraction in a Lincoln-designed data acquisition and analysis processor that utilizes multiple processing elements to achieve a 50 million operations/second computation rate.
7. a Perkin Elmer Model 3252 super-minicomputer for overall system control, higher order logic in automatic detection algorithms, and driving local and remote color displays.

The supporting measurement systems for testing in Memphis include:

- a .25 MW, 5 cm, 1.5 degree BW pencil beam Doppler weather radar from the University of North Dakota (UND) to permit dual Doppler analyses.
- remoted data from an existing FAA Air Route Surveillance Radar (ARSR-1) for aircraft location.
- a 30 unit mesonet (with 1 minute measurement rate) interfaced to the Geostationary Operational Environmental Satellite (GOES).
- data recorded from an operational 6 unit Low Level Wind Shear Alert System (LLWAS) at the Memphis airport.
- an instrumented Cessna Citation II jet aircraft from UND.
- an instrumented Convair 580 turbo prop aircraft from the FAA Technical Center.

Additionally, GOES satellite images and WSR-57 (RRWDS) data are also recorded to facilitate meteorological analysis of salient weather events.

The ability to achieve an adequate weather-to-clutter ratio at the low elevation angles and short ranges associated with Low-Altitude Wind Shear (LAWS) detection has been an important issue for the TDWR. The NEXRAD Technical Requirements (NTR) calls for a 50 dB clutter suppression capability with at least 45 dB clutter suppression being demonstrated in the validation phase testing. Figure 3 shows 50 dB experimental clutter suppression by the testbed against clutter from a microwave tower with a coherent Doppler shifting repeater providing a synthetic weather signal. The suppression in this case is limited by spurious lines from the production line ASR-8 transmitter/receiver used in the testbed. We believe that a transmitter/receiver designed at the outset to achieving the NEXRAD-desired capability should have little difficulty meeting the NTR. Reference 1 describes many aspects of NEXRAD clutter suppression by the use of linear time invariant clutter filters.

Another important issue for the Memphis measurements is the extent to which the LAWS phenomena of greatest concern, microbursts/downbursts, occur in a moist meteorological environment such as Memphis. These phenomena were found to be fairly frequent in the dry subcloud environment of Denver; however, there is currently considerable uncertainty regarding the frequency and (dynamic) generation mechanism for moist subcloud environment microbursts/downbursts. Figure 4 shows some very preliminary statistics on high wind events observed on the 25 station mesonet which was operational in the May-November 1984 period. These data have not been corrected for site obstruction effects; it is anticipated that both more events and more sensors/event will be found in the final summary of the 1984 data.

Figure 5 shows preliminary results of analysis by Marilyn Wolfson of a microburst at the end of Memphis runway 27 that induced a 30.2 m/sec (68 mph) peak wind at mesonet station No. 25 at 1806 CST on 20 October 1984. Before the onset of the microburst, the environmental wind was 7 to 9 m/sec (16 to 20 mph) from the southerly direction. In 2 minutes, the wind reached its peak, followed by a decrease to below 15 m/sec (34 mph) in the next 2 minutes. The duration of this microburst, defined as the period of one-half of the peak windspeed, was 4 minutes.

A detailed analysis of the mesonet data revealed that the microburst was located just behind a gust front, which swept across the Memphis area. Consequently, the area of the microburst, after its dissipation, was replaced by the cold air pushing behind the gust front. Both temperature and pressure changes were characterized by those of a gust front except for a significant pressure drop during the microburst winds.

This microburst was accompanied by a very strong wind shear at low altitude. A hypothetical aircraft penetrating the storm from southeast to northwest would experience a 20 m/sec (39 kts) increase in headwind, followed by a 15 m/sec (29 kts) loss of headwind within approximately 3 km (10,000 ft).

Typical results from one of the correlation tracker/reflectivity map extrapolation algorithms developed at Lincoln for use in NEXRAD are shown in Fig. 6. The algorithm determines the velocity vectors associated with various cells by cross correlating the data from different measurement times and then predicts the reflectivity map at a future time by moving appropriate features of the current map according to the estimated velocity vectors. A Lincoln report (reference 2) describes this and several other tracking techniques as well as the capability of this extrapolation techniques to provide useful 10-30 minute predictions.

Assessment of the utility and validity of the weather products to be supplied to ATC users is an important element of the FAA/Lincoln program. Figure 7 shows a block diagram of the testbed system emphasizing the various display options, which will be utilized in the next few years.

Information on aircraft position are obtained from the Common Digitizer (CD) output of a FAA ARSR for use in tracking the instrumented aircraft and providing position reports for ATC aircraft/weather displays. We plan to test some concepts for displaying regions of hazardous weather together with aircraft position data on color displays in connection with product evaluation tests at the Memphis ARTCC this coming year.

Work is currently underway at Lincoln Laboratory to develop weather image coding techniques that could be used to transmit images to aircraft over the Mode-S data link. We hope to carry out real time testing of the capability as a part of the Mode-S data link flight test program, which will commence this year.

In summary, the FAA is actively engaged in the engineering application of Doppler weather radar research work to achieve an order of magnitude improvement in detection of hazardous aviation weather and provision of the results to principal ATC users. A principal focus for this work is the testbed radar and supporting sensors that will be used for measurements in key meteorological regimes over the next few years to refine and validate the product generation algorithms and displays.

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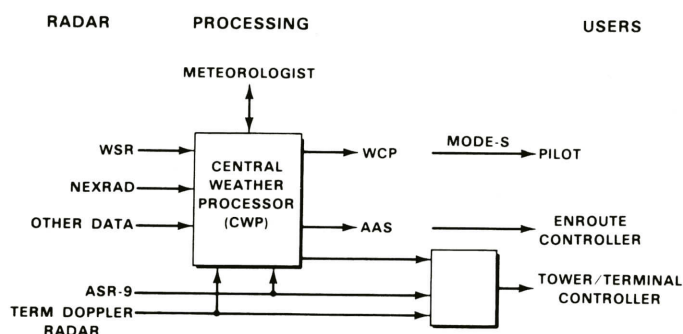


Fig. 1. FAA real-time radar derived weather information system.